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BBC RD 1994/16

Research and Development Report

DIGITAL AUDIO BROADCASTING:
Comparison of coverage at Band II and Band III

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Summary

A Digital Audio Broadcasting (DAB) system capable of reliable reception in vehicles and portables has been developed by the EUREKA 147 project.

This Report describes a set of experiments performed to compare the coverage area when radiating a DAB signal of equal power in Band II and Band III.

It is concluded that a slightly lower level of signal variation is obtained at Band II than Band III. This suggests that a 50% to 99% location correction factor of 12 dB should be used for Band II.

However, the experimental measurements of coverage area have shown that, for equal transmitter powers, the coverage at Band II was considerably less than at Band III. This result was unexpected. The most likely cause of the poor performance at Band II was a much higher level of man-made interference in that Band being generated from the high-power FM transmitter in the area.

Further and more detailed experiments are recommended to investigate the levels of man-made noise at Band II and Band III.

Issued under the Authority of

General Manager
Research & Development Department

Research & Development Department,
Engineering Division
BRITISH BROADCASTING CORPORATION

1994

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1. INTRODUCTION

A Digital Audio Broadcasting (DAB) system capable of reliable reception in vehicles and portables has been developed by the EUREKA 147 project [1]. The aim of DAB is to deliver near-CD quality stereo audio programmes in digital form to domestic receivers.

DAB is based upon a coded-orthogonal-frequency-division-multiplex (COFDM) modulation system [2] which provides rugged performance in the presence of multipath [3]. This allows the service to be designed to serve portable and mobile receivers, which, with their omni-directional antennas and low antenna height, are particularly susceptible to multipath.

It has been noted that to plan DAB services to portable and mobile receivers requires detailed knowledge of the statistical distribution of the received DAB signal. Measurements of the variations in the received signal level have been made to quantify the effect of the frequency and time diversity which is inherent in the modulation system [4]. These include the measurement of the standard deviation of the signal variation in local areas as well as the median signal level.

Earlier work had been carried out to compare the coverage area obtained with different bandwidths of the COFDM signal and to compare the coverage when the signal is radiated on frequencies in Band III and Band IV [4]. This work concluded that the choice of a bandwidth for the DAB signal of approximately 1.5 MHz is suitable because it is still sufficiently wideband to provide a significant benefit in reducing the location variation of the total received signal power, whilst being narrow enough to allow suitable channelisation within the existing frequency bands. It also concluded that a frequency allocation below Band IV is necessary to provide uniform coverage from terrestrial DAB transmitters.

It may be expected, therefore, that the use of Band II, a lower frequency band, would be better than Band III. Although, in the UK, DAB is unlikely to be radiated at Band II for many years, and not until it has effectively supplemented FM for the listener, it is the CEPT's proposed ultimate home for DAB.

Consequently, a further set of tests was conducted to evaluate the performance of Band II. Unfortunately, this work is not possible in the London area because of the large number of FM stations currently broadcasting. As a result, there is not a sufficiently large section of Band II spectrum available in the South East of England for DAB experiments. In July 1991, however, the BBC gave a demonstration of DAB to the Radio Academy in Birmingham. This involved setting up a DAB transmitter on top of an office block in the City Centre. The event provided an opportunity to conduct Band II tests since there was, for a few months, a sufficiently large gap in the spectrum in Birmingham to accommodate a 1.75 MHz bandwidth experimental DAB signal. Note that the final Eureka 147 DAB specification has a bandwidth of approximately 1.54 MHz.

This Report describes the set of experiments performed in the Birmingham area to investigate the effect on the coverage area of radiating the DAB signal at Band II and Band III.

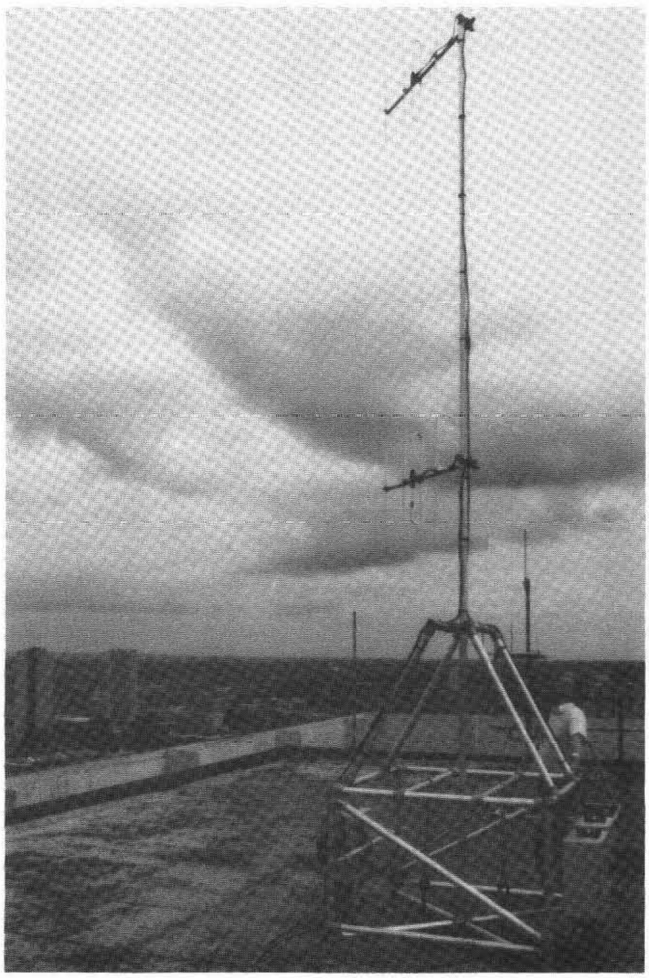

Fig. 1 - The antenna installation on the roof of Cumberland House. (at a height of 70 m a.g.l.)

2. EXPERIMENTAL ARRANGEMENT

2.1 Transmitting equipment

The transmitting equipment was located on the roof of Cumberland House, a seventeen story building in the centre of Birmingham, Fig. 1 *(see previous page)*. A schematic of the transmitting equipment is shown below in Fig. 2. The antennas and weatherproof boxes containing the power amplifiers were mounted on scaffolding attached to the roof. The COFDM transmitter and the rest of the equip- ment were located in a small hut at the end of the building.

The antennas used were vertically polarized 4 element yagis with a gain of 7.5 dBd. The two antennas were mounted one above the other on a 4 metre scaffold pole and were on a bearing of 45°. An e.r.p. of 50 W was radiated on each transmitted frequency. The centre frequencies of the two transmissions were 211 MHz and 100.25 MHz.

2.2 Receiving equipment

Similar receiving, measuring and recording equipment was installed in the same survey vehicle as was used for the previous work in the South London area[4]. A block diagram of the survey equipment is shown in Fig. 3.

The Band II or III signal was received by a quarter-wave whip antenna mounted above a ground plane attached to the vehicle roof-rack. Unlike the previous tests, the two antennas were not fitted simultaneously. Instead only the antenna appropriate to the frequency being measured was fitted. Since the two antennas have the same base fitting they could easily be interchanged between Band II and III measurements.

Two waterproof boxes were fitted beneath the ground-plane, one containing an RF filter and amplifier for Band II, and the other containing a similar arrangement for Band III.

The filtered and amplified RF signal was fed to the inside of the vehicle where the receiving and measuring equipment was situated. For reasons discussed later, additional filters were used for BandII measurements.

As before, 240 V, 50 Hz mains power was supplied from a petrol-powered generator. This was

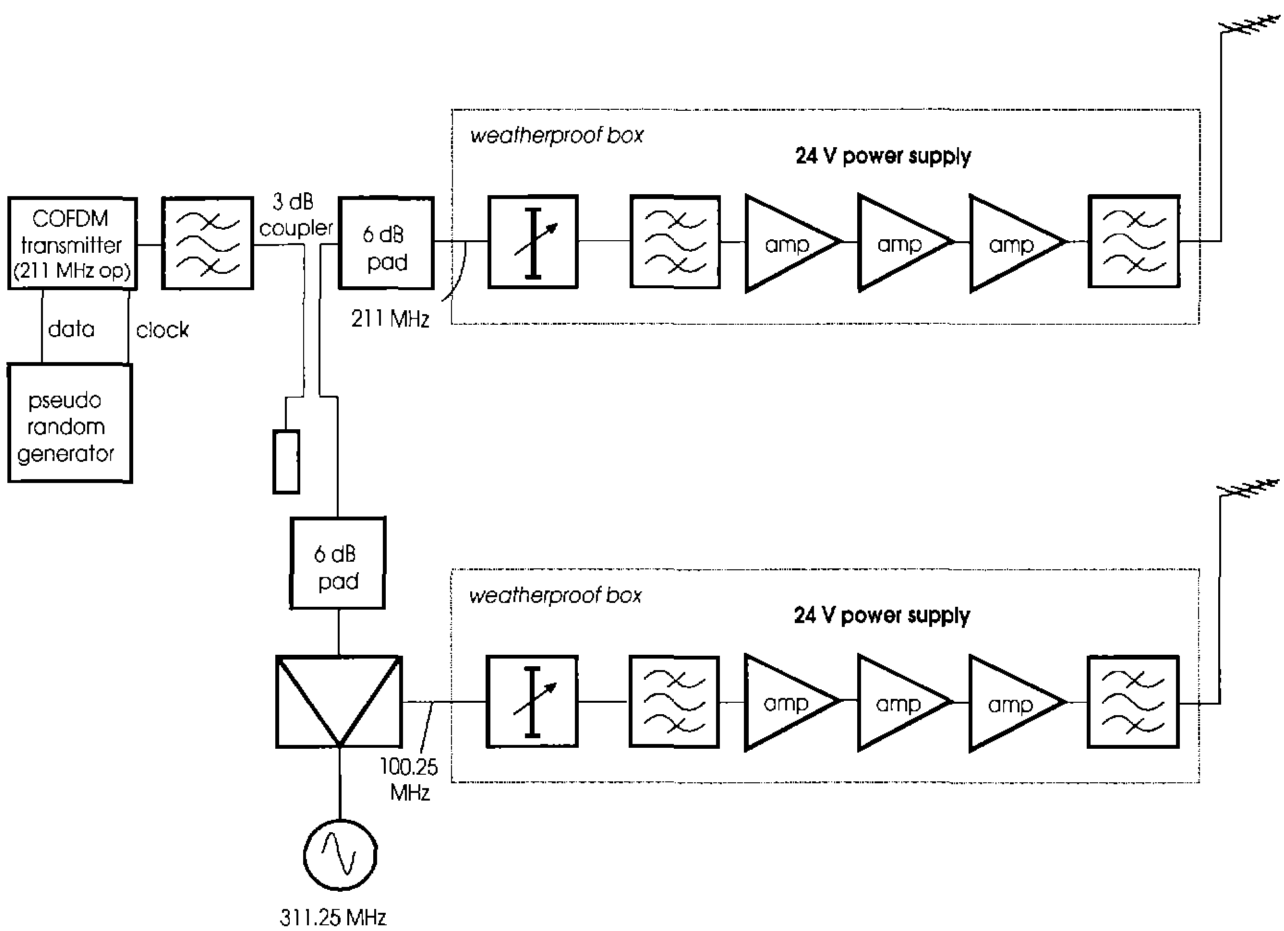

Fig. 2 - Block diagram of the transmitting equipment.

mounted on the rear bumper of the measuring vehicle. To protect the equipment from loss of power and mains-borne interference, an uninterruptable power supply (UPS) was used to condition the supply and provide approximately 10 minutes support in the event of loss of power from the generator. The UPS was mounted in the back of the vehicle, beside the COFDM receiver and oscillator.

During the tests, the transmitted PRBS was received in the vehicle and demodulated. The error rate of received data was measured using a bit error rate (BER) counter connected to the COFDM receiver. A failure indicator was added to provide easy monitoring of when the BER lay in one of three states. These states were as follows:

- a good signal, where the BER was better than 1×10^{-5},
- an errored but decodable signal, where the BER was worse than 1×10^{-5} but better than 1×10^{-1}
- an unusable signal, where the BER was worse than 1×10^{-1}.

An oscilloscope and a spectrum analyser were

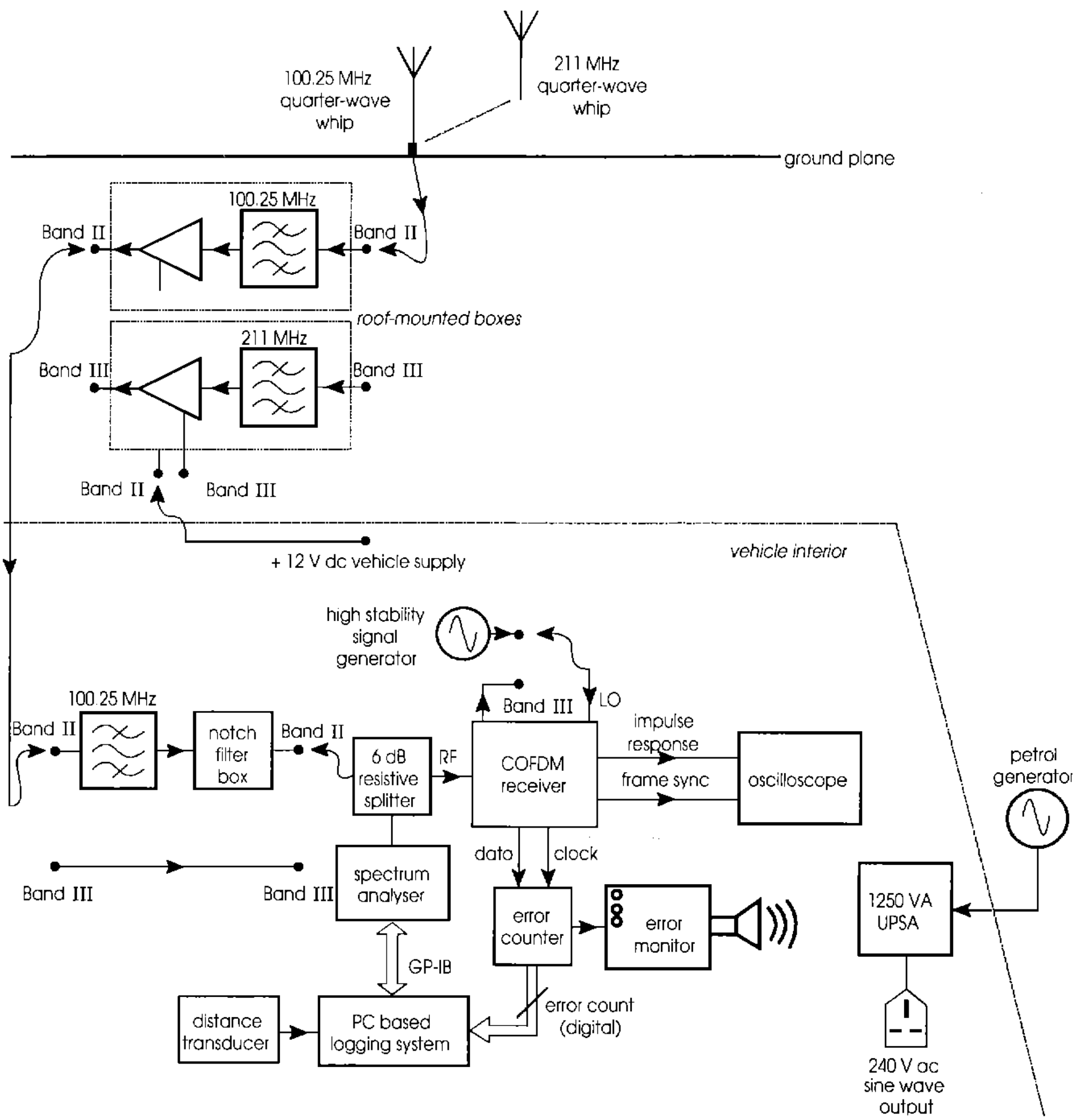

Fig. 3 - Block diagram of the receiving equipment.

incorporated in the measuring equipment. The oscilloscope was used to display the impulse response of the channel, which could be obtained from the COFDM receiver. The spectrum analyser was used to display the received RF spectrum. This information was useful for understanding the cause of failure of the COFDM signal.

A computer-based logging system was also used to record field-strength values. The system was connected to a distance transducer which enabled it to take readings at regular intervals along the road. All readings were labelled with the map grid square in which they were taken.

3. COVERAGE EXPERIMENTS

3.1 Experimental procedure

The survey was limited to an area within the main beam of the transmitting antenna, Map 1*. Two types of experiment were conducted:

- The coverage of the signal was measured by marking the BER category of a particular piece of road on a map.
- The statistics of the signal variations within a small area were measured.

The survey coverage was concentrated on areas where the reception was starting to fail. Initially, the receiving equipment was set to receive the Band III transmissions, and the vehicle was driven around in the area to be surveyed. The DAB reception was recorded on a map in one of three different colours, one for each of the BER ranges discussed above. The vehicle speed during this survey was kept as close as possible to 40 km/h. Then the equipment was set to receive the Band II transmissions, and the test was repeated. Where possible, the same roads were surveyed and the vehicle was driven in the same direction.

Then, signal statistics were obtained from field strength readings recorded by the computer. Readings were triggered by two mechanisms: distance and time. Distance triggers were set at 10 metre intervals, while time triggers were at 2 second intervals. Table 1 is a reproduction from a typical section of the survey data, and shows the two types of readings (each trigger type is shown by appropriate letter indicators, D (distance) and T (time)).

The signal statistics could be calculated from either distance- or time-triggered readings, or from both. The values obtained were almost identical in each case. For subsequent work, both types of reading were used, so that the statistics were based on the maximum number of readings.

3.2 Coverage results

The results of the coverage survey at Band II and Band III are detailed in Maps 2 and 3 respectively, and in summary in Maps 4 and 5.

These results suggest that the coverage at Band II is considerably worse than at Band III. This goes counter to the result expected of better coverage at the lower frequency. Furthermore, the difference is very considerable indeed; the Band II coverage extends to only about 10 – 15 km from the transmitter. Band III coverage, on the other hand, extends for at least 20 km.

3.3 Signal variation results

The location of the squares in which the signal levels were logged (with their terrain classifications) is shown in Map 6.

For each square, the readings were processed to

Table 1: A copy of a typical section from a computer read-out.

Trig by	Time	Dist.	F.Str.
T	289	677	60.2
D	290	682	78.3
T	291	684	78.3
T	293	687	75.2
T	295	687	70.0
T	297	687	69.8
T	299	688	73.5
D	300	692	66.3
T	301	693	66.3
D	302	702	76.2
T	303	702	76.2
T	305	711	72.3

Trig. by = Triggered by
Time = Time (Secs)
Dist. = Distance (m)
F.Str. = Field Strength (dBµV/m)
T = Triggered by time
D = Triggered by distance

* All maps are placed in Section 10 at the end of the Report.

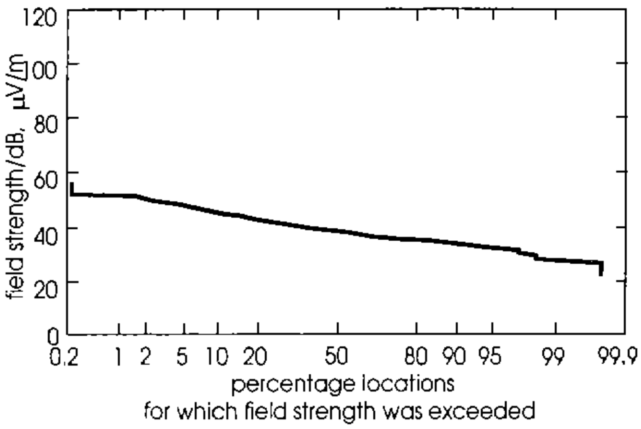

Fig. 4 - Typical cumulative distribution function of the data in a local area.

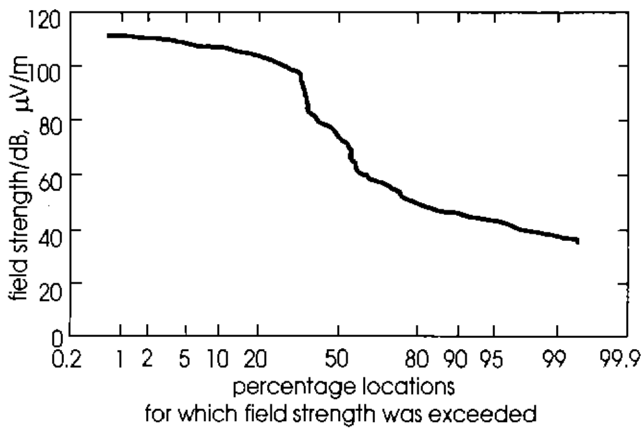

Fig. 5 - Example of anomalous cumulative distribution function of the data in a local area.

produce a graph of field strength versus percentage of locations for which that field strength was exceeded. From this, the median values of field strength and the standard deviation of the variation, were calculated

The results for each area of median field strength and standard deviation are respectively shown for Bands II & III in Maps 7 and 8.

A few of the areas show unexpectedly high levels of signal variation at Band II. Examination of the signal statistics shows that, in these areas, the approximation of the variations as a log-normal distribution is erroneous. Fig. 4 shows the signal variation in a typical area, and Fig. 5 shows the variation in one of these anomalous areas.

The cause of the distribution shown in Fig. 5 is unknown. However, it was found that these cases occurred close to the DAB transmitter site. It is possible that they may have been caused by surveying in an area where two, very different propagation conditions occurred. In some places in the area a direct path to the transmitter existed and in others the direct path was blocked. In locations so close to the transmitter the change in level would be considerable.

For the purpose of determining the average standard deviation of the signal variations, the areas which exhibited this anomalous propagation were ignored. Such areas are noted with a * in Map 7. The weighted average of the standard deviation of the signal variation at Band II and Band III was calculated. The results are summarised in Table 2.

4. OTHER FACTORS AFFECTING COVERAGE

Two possible causes were suggested to explain

Table 2: Comparison of signal variation at Band II and Band III.

Terrain classification	Number of 1 km by 1 km areas	Standard deviation of signal variation at Band II (dB)	Standard deviation of signal variation at Band III (dB)
Dense Urban	1	8.5	10.5
Urban	3	6.8	8.0
Suburban	9	5.9	5.7
Rural	3	3.9	5.1
Total	16	–	–
Weighted average of signal variation for all terrain types	–	6.3	6.9

the poor coverage obtained at Band II.

4.1 Interference

There are many high-power broadcast transmissions at frequencies close to the band occupied by the experimental DAB signal. Particularly significant in this area were Radio 1 on 97.9 MHz and Buzz FM, an incremental community station, on 102.4 MHz. Although these frequencies do not fall within the 1.75 MHz wide DAB channel (99.375 to 101.125 MHz), they were sufficiently close to impair the performance of the receiver.

Of the two main interfering transmitters, the community station was the least troublesome since it is only a 40 W transmitter situated in the city centre. Consequently, it only represents a real problem close to the centre. Radio 1, on the other hand, is a 250 kW transmitter at Sutton Coldfield, quite close to the area of the survey. In some parts of the area this could easily saturate the front end amplifier.

In order to overcome the problems of interfering FM transmitters, an additional Band II RF filter was inserted in the system.

In addition to broadcast transmitters, however, the experimental receiver itself was found to radiate strongly in Band II. These spurious emissions occurred at a large number of frequencies, one of which was in the band occupied by the DAB signal. Additional earthing and screening was added to reduce this interference to a negligible level.

The extra filtering used for Band II measurements introduces additional attenuation between the output of the front-end box and the input of the receiver. In order to determine the effect of the extra filter attenuation, a small section of the Band III survey was repeated with 8 dB of attenuation between the top-box and receiver input. This corresponds approximately to the filter loss. The area chosen was the eastern part of the test area between Lea Marston and Atherstone. It was found that the coverage was only very slightly degraded by the extra attenuation. It certainly does not account for the large difference between the Band II and Band III results.

4.2 Man-made noise

It was expected that there would be more background RF noise received at Band II than Band III. The effect of noise generated by the vehicle and the experimental measurement equipment was examined. However, this was shown not to be the major contribution to the levels of man-made noise in the area.

Measurements of the levels of man-made noise were made at a number of locations in the test area at Bands II and III. The results in Table 3 show that, on average, the levels of noise in Band II were around 10 dB higher than in Band III. More significantly, the level of man-made noise in Band II was found to increase substantially near to the high-power transmitter at Sutton Coldfield. The relationship is shown in Fig. 6.

Therefore, it is suggested that the man-made noise found in Band II was generated by the high-power FM transmitter nearby. This amplifier noise, whilst very low in level, was still significantly higher than the thermal noise level at receiving points close to the high-power transmitter.

5. DISCUSSION

The experimental work has demonstrated that

Table 3: Levels of man-made noise at selected points in Birmingham.

Location	Distance from the Sutton Coldfield transmitter (km)	Band II noise field strength (dBμV/m)	Band III noise field strength (dBμV/m)
Pebble Mill	17.6	17.6	11.2
Langley Hall	6.2	28.6	10.2
Walmley Road	6.5	24.2	11.3
Nether Whitacre	14.0	17.7	8.4
Earlswood	25.8	17.0	–
Average	–	21.0	10.3

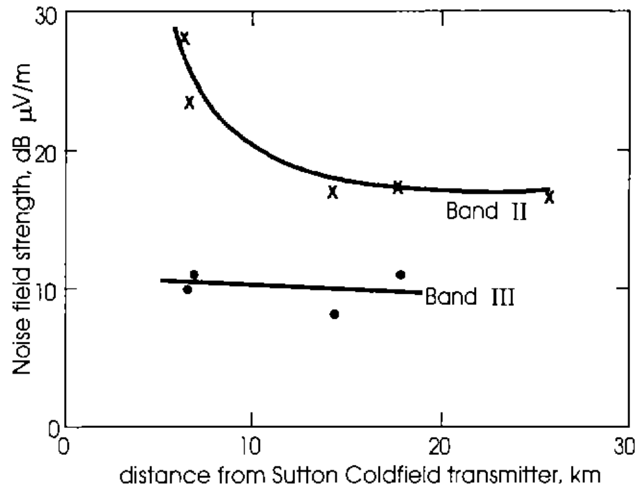

Fig. 6 - Man-made noise at Band II as a function of distance from the Sutton Coldfield transmitter.

the median signal level measured from two transmissions of a DAB signal, one at Band II and one at Band III, are very similar. The results also show that there is slightly less signal variation in a small area at the lower frequency. Both these results were expected.

The average standard deviation of signal variation was found to be approximately 10% lower at Band II than at Band III. The Band III value was found to be similar to that measured over a more extensive area in earlier work[4]. As a result, the area in which these measurements were made is believed to be representative. Reducing the value measured at Band III in earlier work by 10% suggests that a standard deviation of variation in signal level of 5 dB at Band II can be expected. The corresponding 50% to 99% location variation correction factor is approximately 12 dB.

However, the area coverage of the Band II signal was found to be significantly smaller than the area coverage at Band III, for the same e.r.p. The discrepancy was found to be due to higher levels of man-made noise at Band II than Band III.

To some extent, higher levels of man-made noise are to be expected at Band II than Band III[5, 6]. More recent measurements made by the BBC have shown that the level of man-made noise, in a wide range of terrain, to be around 10 dB higher in Band II than Band III. However, the additional experimental work suggests that, in this case, the coverage of the DAB signal at Band II was limited by the transmitter noise radiated by the high-power FM transmitter nearby. This situation is unrepresentative, as, in a broadcast environment, it is unlikely that ultra-low power DAB transmitters would be installed at frequencies close to high-power non-DAB transmitters. If the DAB transmitter had an e.r.p. of a few hundred Watts, or even 1 kW, then the edge-of-service area would have occurred at a distance sufficiently far from the FM transmitter that its interference (constituting noise) would not have been significant. Furthermore, if DAB transmissions were moved into Band II, it would be expected that high-power FM transmitters would be closed down.

6. CONCLUSIONS

Experimental measurements have been made to compare the coverage expected from a DAB service operating in Band II and Band III.

The results of analysis of the measured Band II and III signal levels, made in the Birmingham area, show that similar median values are found for both Bands. A slightly lower level of signal variation is recorded at Band II, suggesting that a 50% to 99% location correction factor of 12 dB should be used for this Band.

Measurements of the coverage areas have shown that, for equal transmitter powers, the coverage at Band II was considerably worse than at Band III. This result was unexpected. The most likely cause of the poor performance at Band II was the presence of much higher levels of man-made interference at these frequencies than at Band III.

A preliminary study suggested that the additional noise at Band II was largely caused by amplifier noise from a nearby high-power FM transmitter operating on a frequency close to that occupied by the DAB signal. This problem should not be evident if DAB services are moved into Band II, and the near frequency high power FM stations closed down.

7. RECOMMENDATIONS FOR FURTHER WORK

Further experiments are recommended to investigate the levels of man-made noise at Band II and Band III in more detail.

In the event that transmitters are to be installed at Band II, further measurements of DAB signal level and variations are recommended in a wider range of terrain types.

8. ACKNOWLEDGEMENTS

The authors would like to thank S. Wakeling, K. Murdoch, D.S. Cox, J.H. Moore, G. Moyle, P.N. Tudor and P.R. Durrant, for their work in gathering and analysing the experimental results.

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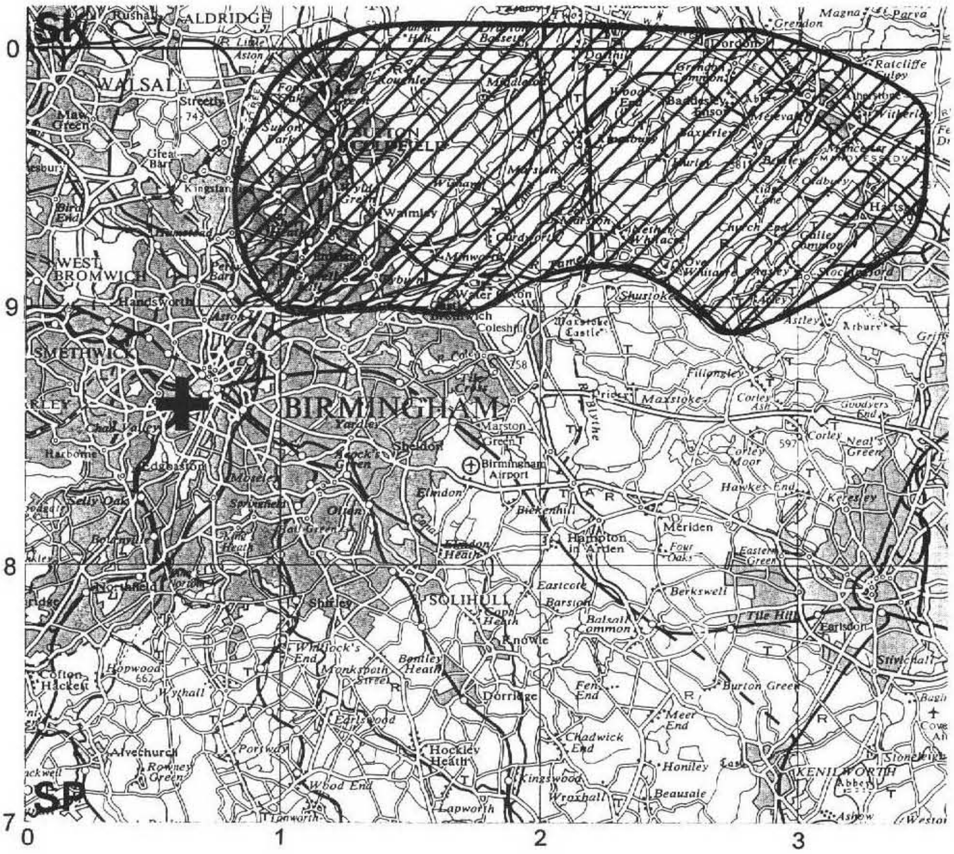
10. SURVEY MAPS

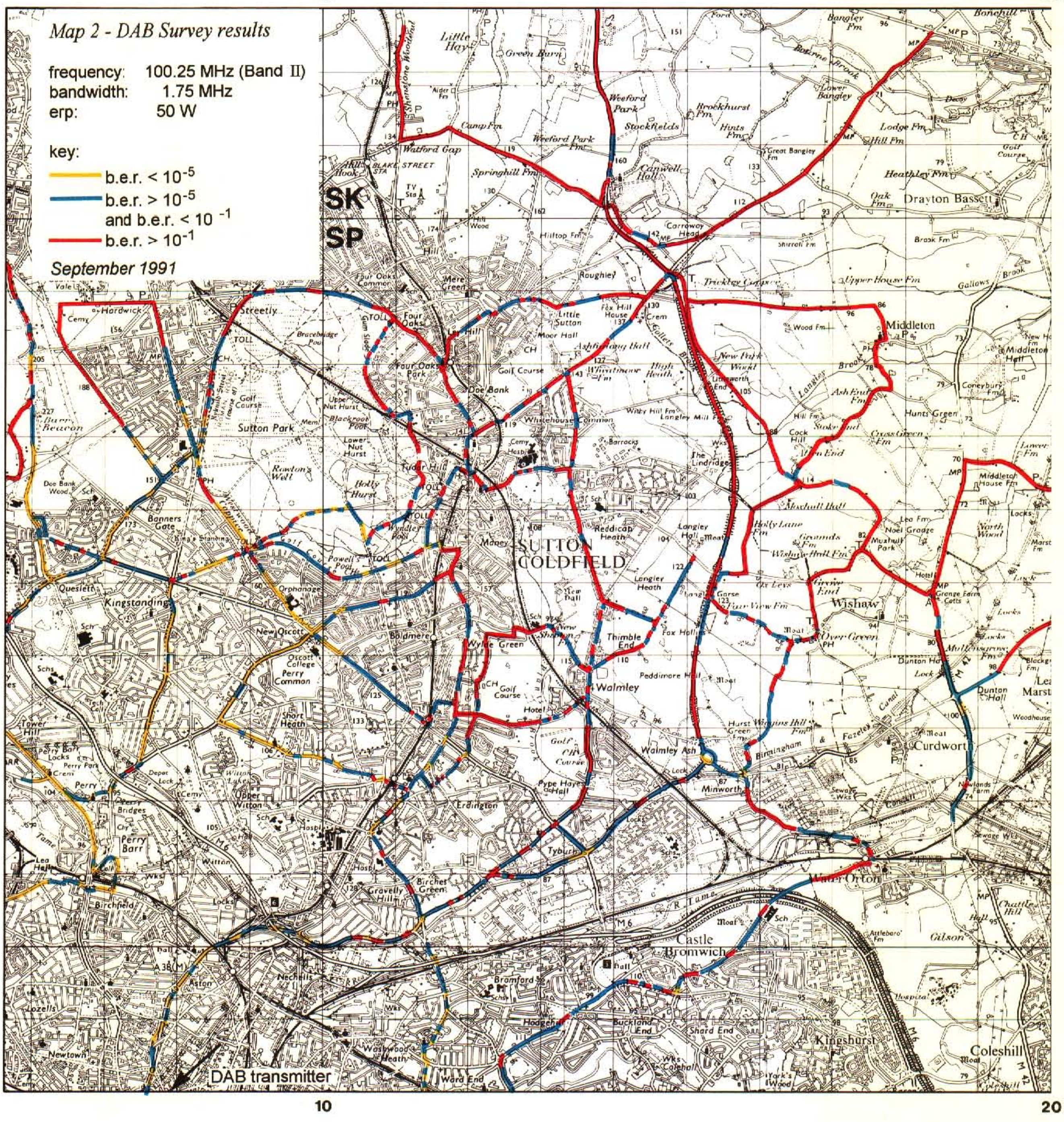


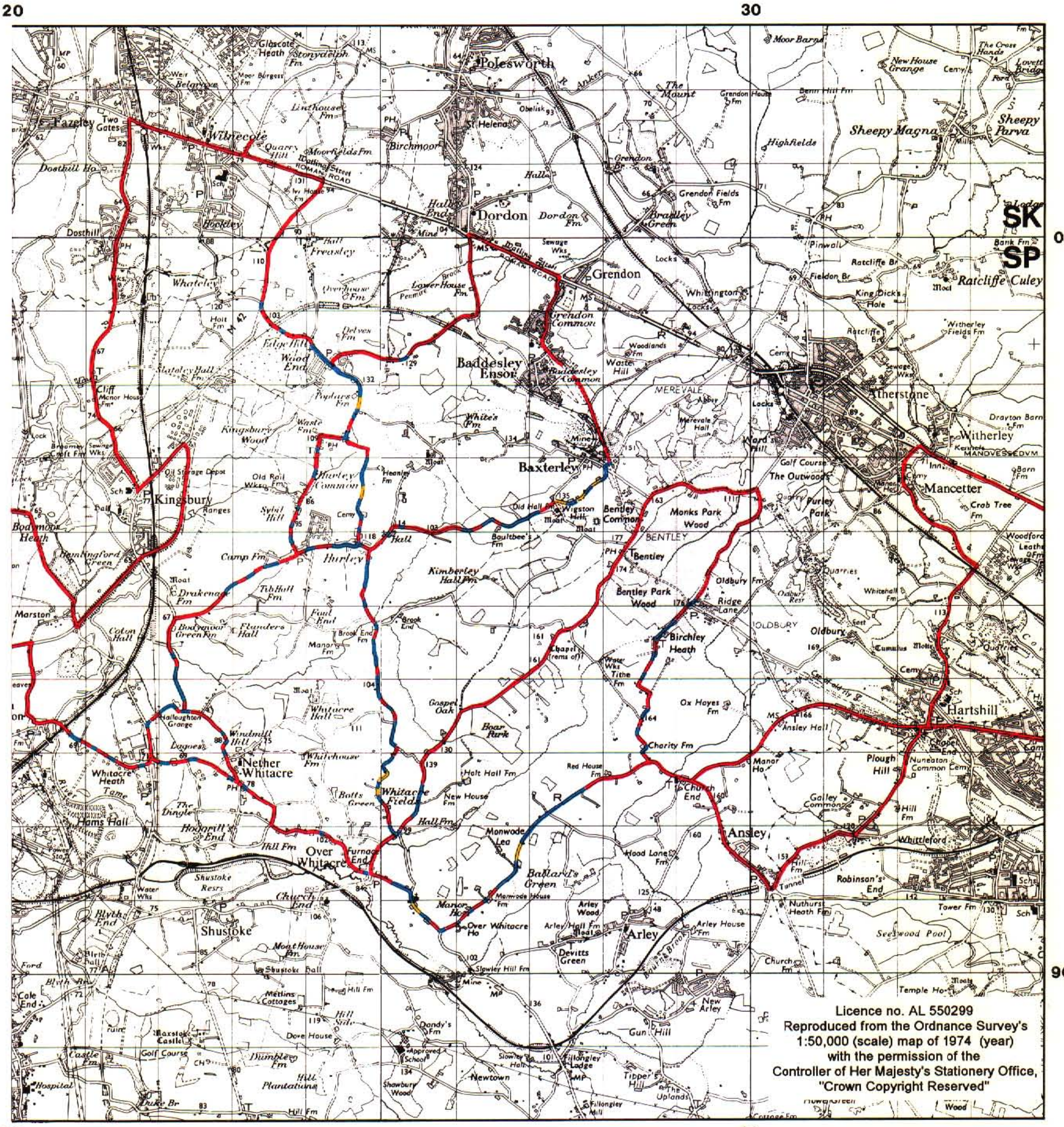
KEY:

transmitter

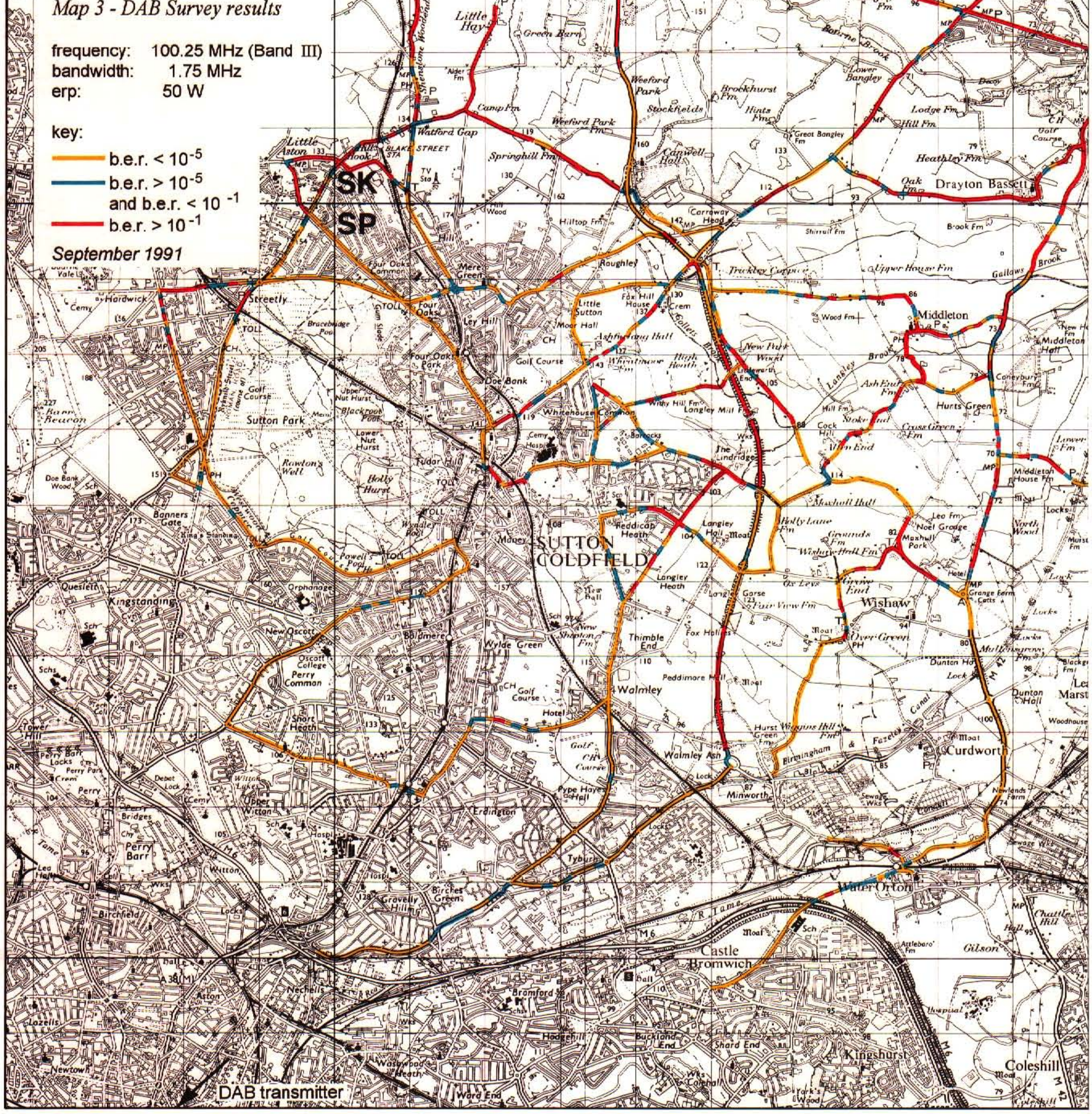
survey area

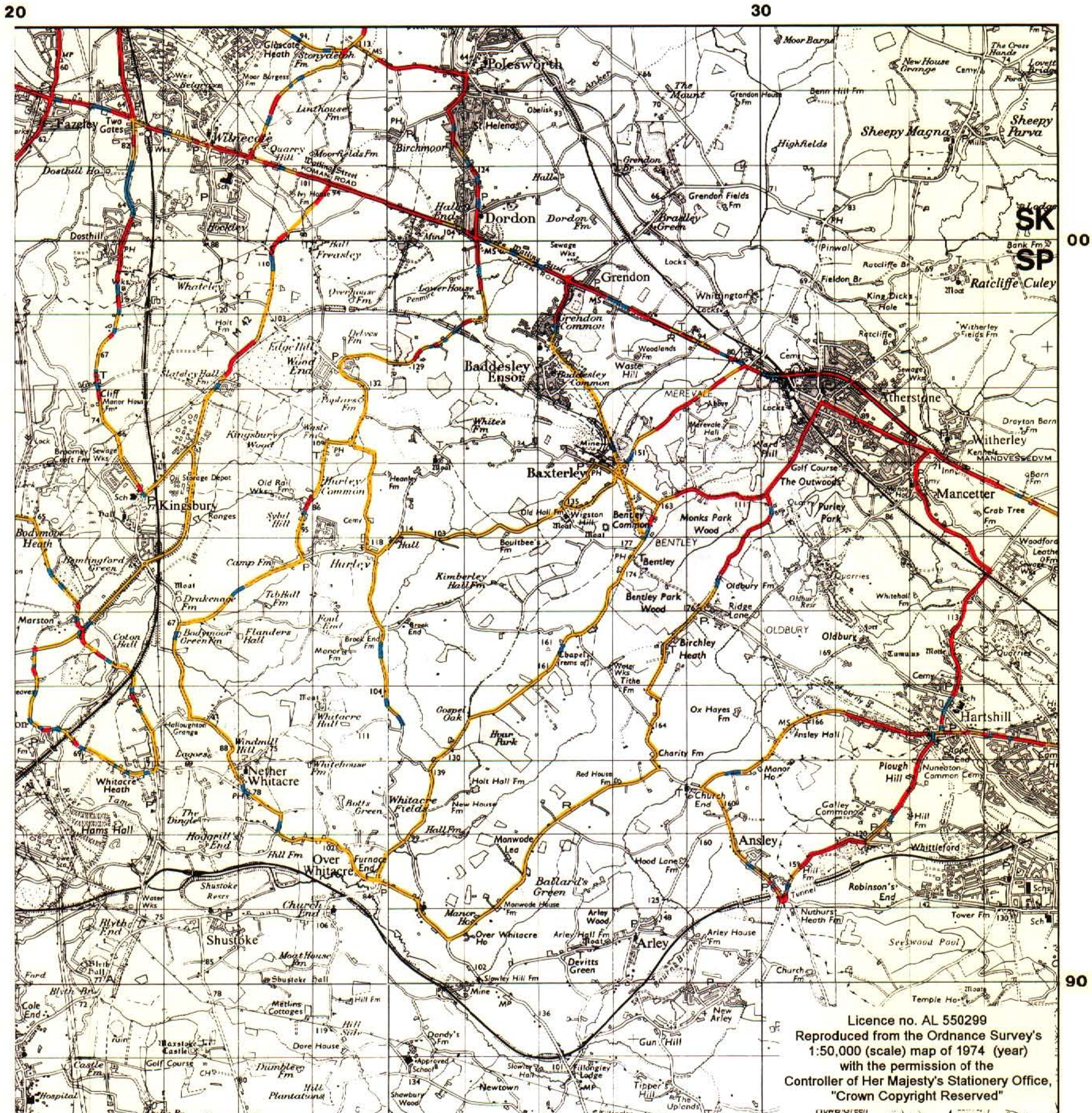
Map 1: Location of the transmitter and the survey area.


Map 2 - DAB Survey results
frequency: 100.25 MHz (Band II)
bandwidth: 1.75 MHz
erp: 50 W
key:
b.e.r. < 10-5
b.e.r. > 10-5 and b.e.r. < 10 -1
b.e.r. > 10-1
September 1991
DAB transmitter
SUTTON COLDFIELD
SK
SP
10
20
00
90

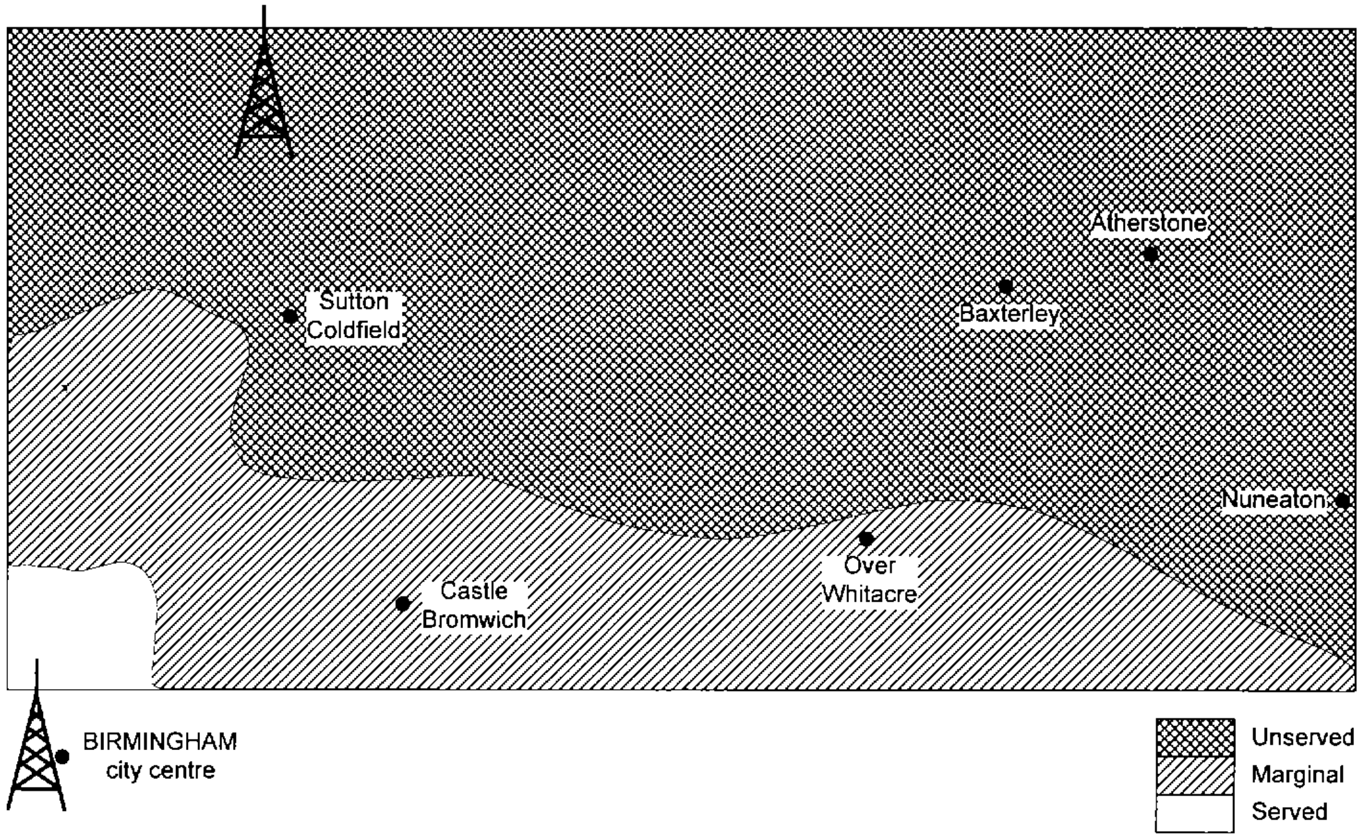


Map 2: DAB survey results for Band II at 100.25 MHz.

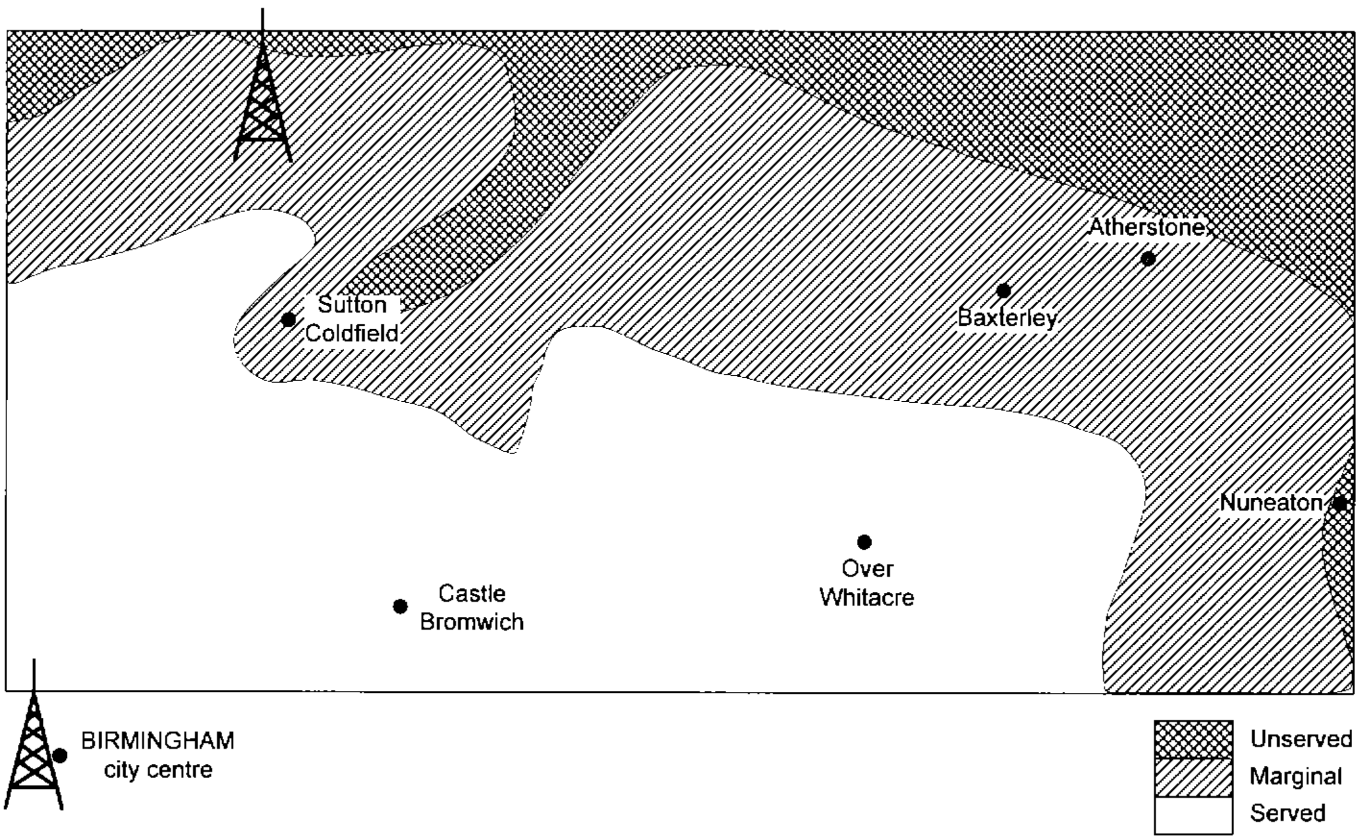

10
20
00
90
Map 3 - DAB Survey results
frequency: 100.25 MHz (Band III)
bandwidth: 1.75 MHz
erp: 50 W
key:
b.e.r. < 10^{-5}
b.e.r. > 10^{-5} and b.e.r. < 10^{-1}
b.e.r. > 10^{-1}
September 1991
SK
SP
SUTTON COLDFIELD
DAB transmitter



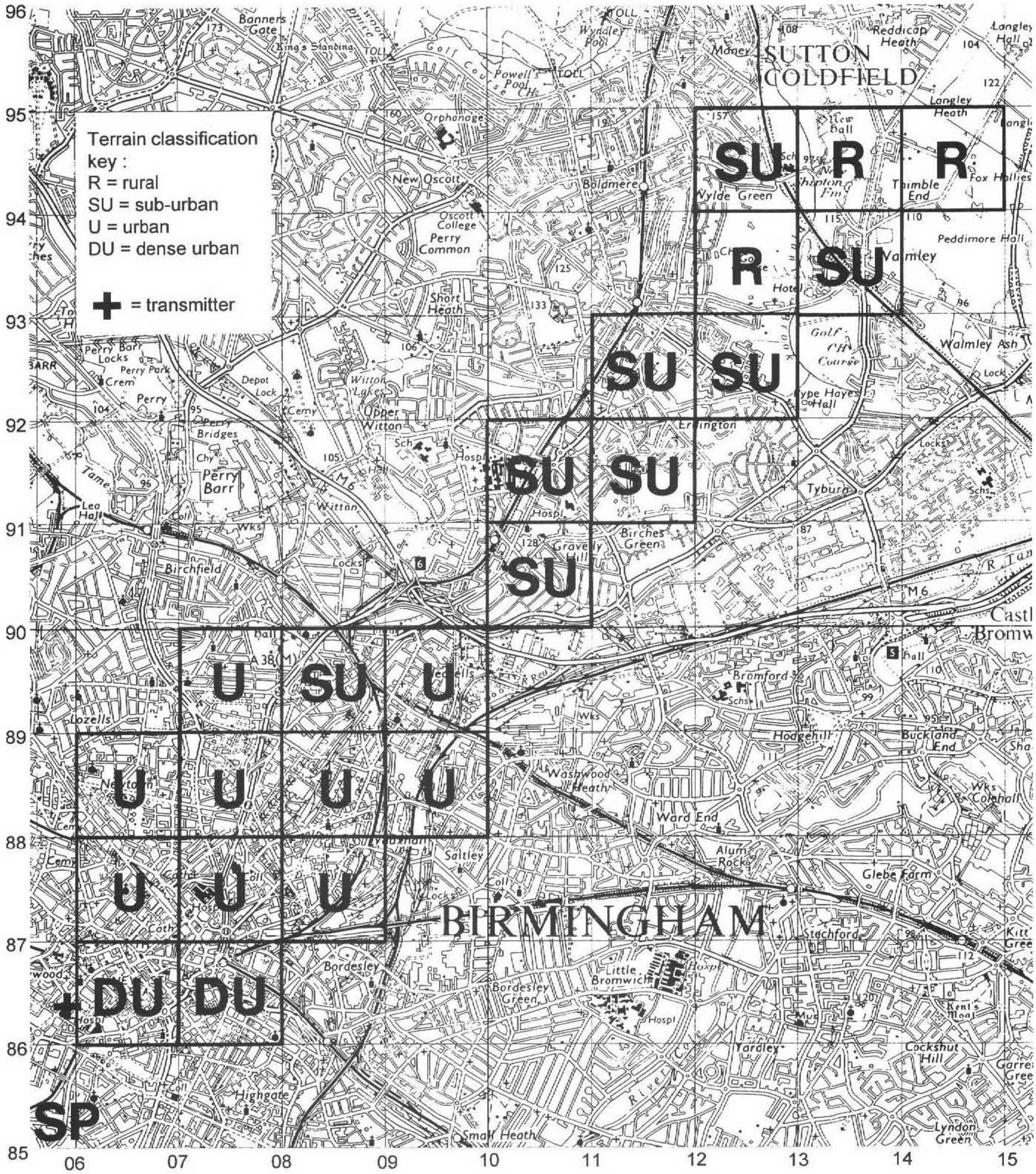
Map 3: DAB Survey results for Band III at 211 MHz.



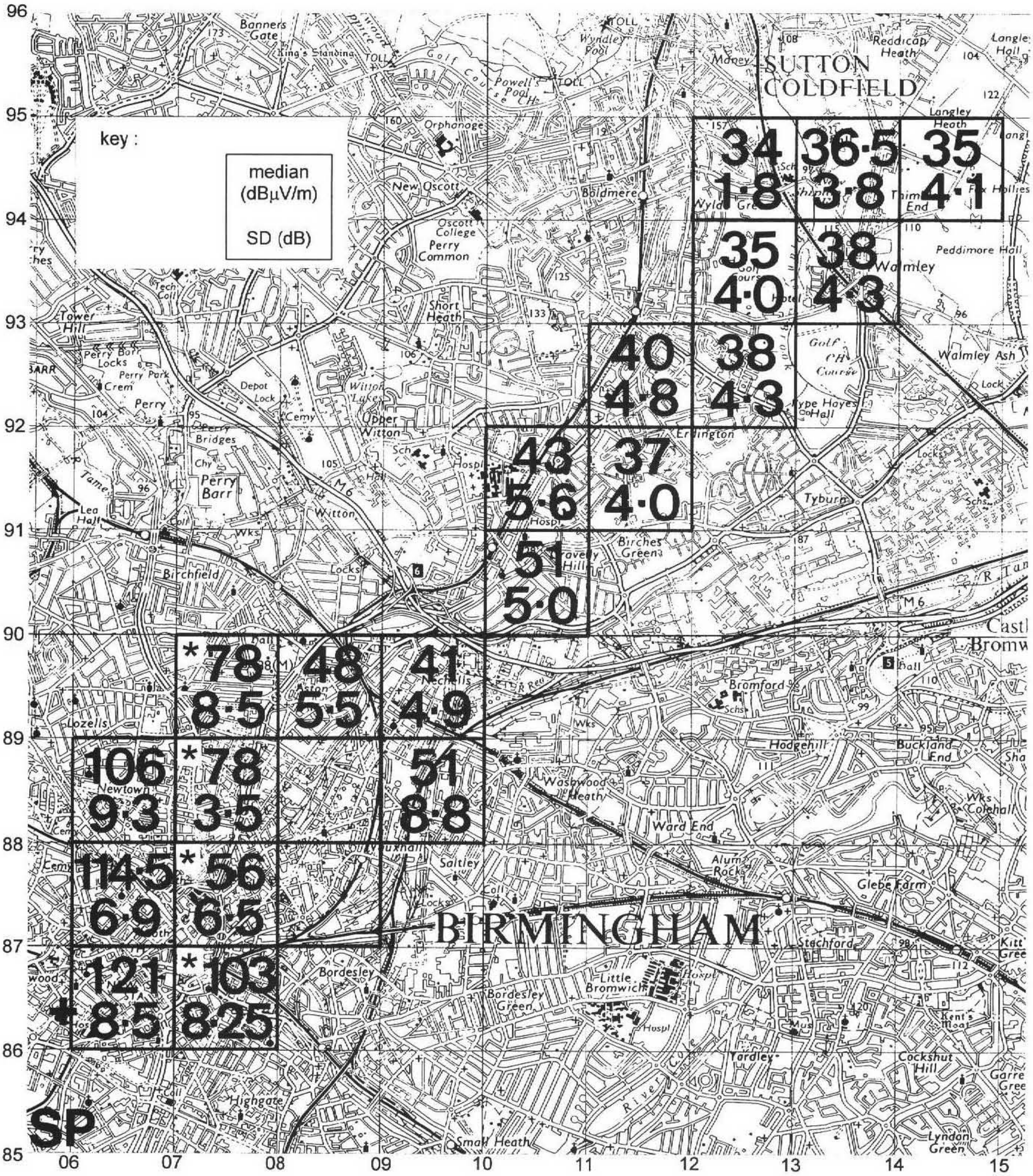
Map 4: Simplified coverage of Band II.



Map 5: Simplified coverage for Band III.

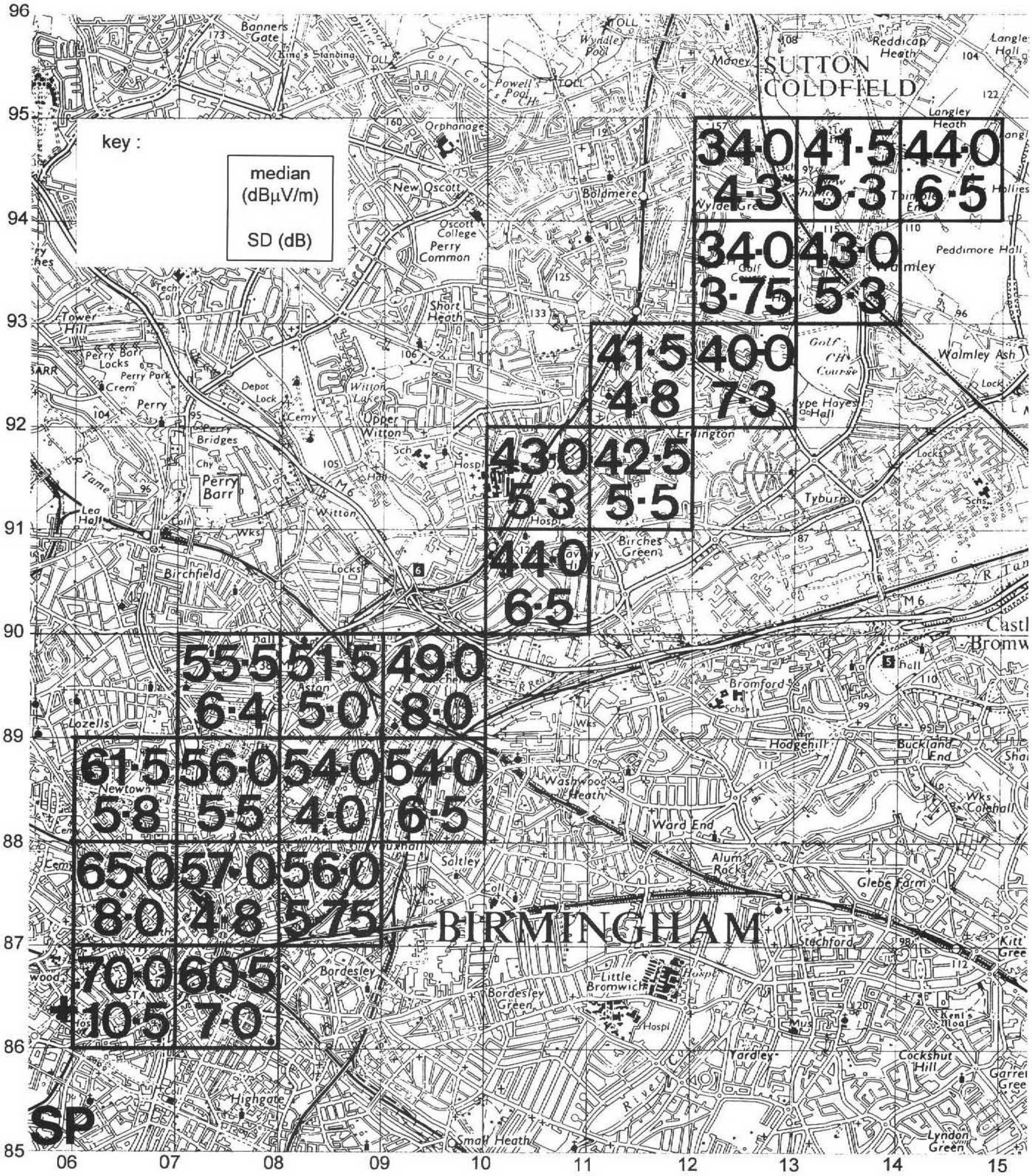


Map 6: Survey area for the logged data.



Map 7: Summary of data statistics at Band II.

∗ *eliminated as they do not have a log-normal variation*



Map 8: Summary of data statistics at Band III.

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